Virtual Worlds as Information Spaces: Supporting Semantic and Social Navigation in a shared 3D Environment

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Abstract—**Virtual worlds are a popular medium for communication and collaboration in 3D and they are being used as shared information spaces in various application areas. However, compared to traditional hypermedia and web-based information systems they offer little support for semantic and social navigation. In this paper, a framework for enhancing virtual worlds with metaphors that support improved semantic and social browsing in the 3D environment is proposed, and an integrated architecture for their interface with external information sources through the employment of Linked Data is presented. In order to assess the effectiveness of the proposed approach, a prototype system has been implemented and accordingly evaluated.**

Virtual Worlds; linked data; metaphors; social navigation; semantic navigation; information spaces

I. INTRODUCTION

Virtual Worlds (VWs) are computer-generated environments, in which multiple users act, communicate and collaborate using embodied representations in a shared space [1]. An important characteristic of these environments is the sense of presence that they generate to their users, i.e. the feeling that they are part of the artificial environment they are interacting with [2,3], as well as the relevant sense of co-presence, i.e. the awareness of other users collocated in the 3D space [4]. The popularity of VWs is rising in the last few years (e.g. the world of Second Life has over 20 million registered users[1]), which is not difficult to explain: the freedom given to users to express themselves, to experiment, to configure their representation and to develop a kind of social life in the artificial environment have shown to be highly desirable [5].

A prospective application area of VWs beyond being a place for user communication and social interaction is to serve as an information space, i.e. to contain artifacts that convey information, either explicitly or on demand, about a specific subject. Typical examples include virtual museums and exhibitions [6], digital libraries [7], information visualization environments [8] and educational places [9]. A common characteristic of such cases is the existence of a large collection of artifacts placed in the environment that have some 3D representation and are possibly associated with additional information presented in various forms (e.g. text, video, animation) within or outside the virtual space. Dourish and Chalmers [10] present three modes of navigation in information spaces: *spatial*, *semantic* and *social*. Spatial navigation is based on the arrangement of information elements (or, artifacts) in their presentation space, semantic navigation is the following of links to other artifacts with semantic relevance, and social navigation is driven by the actions and preferences of other users in the information space.

Until now, VWs were considered as best suited for spatial navigation, as they employ navigation metaphors that mimic (or sometimes enhance) traveling in physical space. However, in the case of VWs acting as information spaces, spatial navigation alone is not enough. Users wish to follow semantic links and social trails during their search for information. Jeffrey and Mark [11] have argued that navigation within a VW could be considered social navigation, due to the fact that the actions of others in the shared space influence the users' actions. This is true, but it is highly restricting compared to Web applications that support social navigation. The reason is that the only perceived user actions in the VW are of those users who are directly visible at that time, whilst on the Web visitors can indirectly get information about the actions of other users. Moreover, visitors of a VW are restrained to an isolated environment without any direct access to other worlds or information spaces. This derives from the fact that VWs' creators are more concerned in attracting as many visitors as possible than agreeing upon the necessary standards and communication protocols that will result in the creation of interoperable worlds, capable of providing their users the opportunity to become members of an integrated environment consisting of diverse yet interoperable worlds or information spaces. Following from the above observations is the fact that although today's VWs may be used as shared information spaces in various application areas, they offer little support for semantic and social navigation compared to other means of accessing information.

In this paper we investigate possible visualization metaphors and interaction techniques that may be used in VWs in order to allow for improved semantic and social navigation of their inhabitants. In this context, we propose the concept of Thematic Virtual Worlds, i.e. shared 3D environments

[1] User Metrics for Second Life: http://secondlife.com/xmlhttp/secondlife.php, [accessed: 4/1/2011]

enhanced with social and semantic navigation metaphors, and we present an integrated framework for implementing them. Moreover, we facilitate the creation of intreroperable, open VWs that also provide the opportunity to their visitors to interact with the external information spaces. This is achieved through the employment of "linked data", which is described as a method of exposing, sharing, and connecting data via dereferenceable URIs on the Web. As a case study of the proposed framework, we have set up a virtual gallery and performed a user study in order to evaluate its usability and to gain empirical observations about the usage of the social and semantic features of the environment.

The rest of the paper is structured as follows: in the next section we further explain the need to enhance VWs with semantic and social aspects and we present the background work towards this goal. In Section 3 we introduce our proposed framework, emphasizing in the novel features of the environment and describing its architecture. Section 4 presents a case study of the proposed framework, describes the user evaluation process and displays the results. Our conclusions are presented in Section 5.

II. BRIDGING THE SEMANTIC, SOCIAL AND 3D SPACE

Virtual Reality applications are based on the metaphor of an artificial space, in which users can navigate from an egocentric point-of-view and can interact with its contents in real time in a physical and intuitive manner. Therefore, a fundamental element of all such environments is the existence of a 3D space that contains a collection of objects and a set of rules that govern their behavior. In today's VWs this metaphor is extended by allowing the coexistence of multiple users, embodied as avatars in a shared space. In this case, the existence and actions of others can be immediately perceived, thus social interactions such as communication and collaboration can be supported within the environment. VWs, can be, therefore, accounted as social spaces, in the sense that they contain a user community and support mutual awareness and interaction. Finally, in the case of information-rich VWs, one may distinguish a third kind of space, the semantic space, which contains the attributes, concepts and relations that refer to a subset of the 3D objects, the information artifacts. The goal of our research is to propose new representations for the seamless integration of these three spaces into an enhanced environment that combines the advantages of VWs, information spaces and social networks.

A. *Virtual Worlds as Information Spaces*

VWs is a special kind of environment, not widely used until a few years ago, with major differences as compared to the Web and its dominating hypermedia metaphor. The elements are not arranged within a page (which can be easily "explored" using the scroll bar), but within a shared 3D space. Given that the visibility is limited (e.g. one cannot see behind walls), a lot of traveling is required from the users to explore the environment and search for information artifacts. Furthermore, VWs cannot be "hyperlinked" to each other due to a lack of common platform; each world has its own user base and content and no sharing is possible. The only equivalent of hyperlinking in 3D environments is the ability to "teleport" the user to distant places. However, similarly to the hyperlink metaphor, extensive use of this kind of navigation may distort the users' sense of presence and cause disorientation [12]. According to the VW paradigm, each VW is quite often isolated from the surrounding environment that many times consists of others, potentially similar worlds or completely diverse information spaces (e.g. wikipedia). VWs resemble neighboring walled gardens, where visitors of one garden have to climb a wall (e.g. by employing a search engine) in order to move to another one. As a consequence, visitors of a VW are restrained to an isolated environment without any direct access to other worlds or information spaces.

B. *Semantic Navigation in Virtual Worlds*

Supporting semantic navigation in VWs can be achieved by letting users explore the information space based on semantic relationships between its elements. This ability is therefore based on two distinctive features: a) the representation of the semantic space, i.e. the assignment of semantic properties to the objects of the environment and the search for similarities between them and b) the metaphors and interaction techniques for the visual representation of semantic links and the user navigation among them. The semantic representation of artifacts (or, resources) is an issue that has been extensively researched in Web-based information systems. On the other hand, the visualization of semantic associations between elements is still an open issue. The spatial arrangement of items based on their semantic proximity is a simple solution that is, however, restricted by the dimensionality of the 3D environment and the inherent need for realistic space representations in VWs. Therefore, additional visualizations that associate spatially distant elements based on one or more common properties must be employed. Characteristics such as user customization and adaptivity of semantic links may be also preferable, as these features are expected to simplify the user interface and reduce information overload.

The use of annotations, i.e. the association of VW elements with additional semantic information is a metaphor that has been utilized in various application areas (e.g. [13] – Immersive Redliner). Polys and Bowman [14] present a review of design approaches for the presentation of abstract information in virtual environments. They focus on the visualization and layout of annotations and on displaying their association with 3D objects. Bazargan and Falquet [15] also present and classify a number of techniques for representing non-geometric information in virtual environments. A generic environment for adding semantic annotations in virtual environments is presented in [16].

Techniques to visualize associations between information artifacts have been used at the field of information visualization. In this case, researchers have proposed 3D representations of linked documents in which users can navigate and search for information. A commonly used metaphor is a 3D graph, where nodes represented as 2D or 3D objects correspond to information elements and links correspond to lines connecting them. Andrews [8] presents a tool for information visualization, in which a hierarchical collection of documents is mapped as an "information landscape", i.e. a 3D graph of interconnected documents. DocuWorld [17] is a prototype for the 3D visualization and navigation of a document collection. It presents metadata and semantic associations between documents and dynamically rearranges them depending on the user task. StarWalker [18] is a multi-user virtual environment that presents semantically organized information. It visualizes documents as spheres and their semantic relations as links connecting them, and has been used as a testbed to study the behavior and search strategy of users in collaborative information retrieval tasks.

C. Social Navigation in Virtual Worlds

A basic prerequisite for social navigation is the awareness of the presence and actions of others. In the case of VWs, the perception of other avatars is conveying information about where they are, where they are looking at and what they are doing. However, this information is spatially and temporally restricted; only the avatars that are online and stand within the user's field of view are perceivable and, thus, it is only the behavior of this limited number of visible users that drives social navigation. The problem of spatial restriction can be overcome by displaying the position of other online users in a mini-map, i.e. a small top-down view of the environment that is being used as a navigational aid in VWs [19], and/or by adding textual descriptions of critical user actions. Concerning past activities, Grammenos et al [20] have proposed the visualization of user trails as a means to support social navigation. Movements and actions of users leave trails that appear in the environment and can be perceived later on by others. They propose the metaphors of footprints for user navigation, fingerprints for user actions and fossils as generic landmarks that can be left in places of special interests.

III. PROPOSED FRAMEWORK

In the proposed framework, we attempt to apply the functionality and search strategies found in hypermedia information spaces in the context of 3D multi-user environments. We propose an integrated architecture that introduces a number of metaphors in order to enhance the VWs paradigm with semantic and social navigation support.

First, we define the concept of a '*Thematic Virtual World*' as a VW related to a certain subject (or theme), that aims to bring together people interested in it and lets them acquire and exchange information from their interaction with the environment and with each other. Therefore, the goal is to disseminate and extend a knowledge corpus within a VW and to support the emergence of virtual communities and special interest groups. Possible application areas that could benefit from the concept of Thematic Virtual Worlds are: virtual museums, digital libraries, virtual educational environments, knowledge communities and serious games.

A Thematic Virtual World consists of:

1. An *interactive 3D environment* possibly containing a set of rules that govern the behavior of its elements.

2. A *formal ontology* that contains all the concepts related to the theme.

3. A set of *information artifacts*, i.e. elements of the environment that are related to concepts of the ontology and may possibly be linked to external sources of information.

4. A *user community* that may enter the 3D environment as avatars. The members of the community are related to concepts of the ontology in terms of their knowledge and interests.

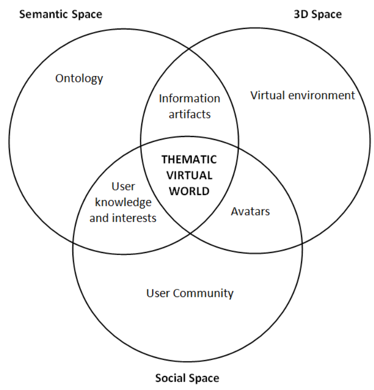

Figure 1. The concept of 'Thematic Virtual Worlds'.

Fig. 1 depicts the concept of Thematic Virtual Worlds as the intersection of semantic, social and 3D space. The requirements in terms of functionality towards this goal, as identified in the previous sections, can be summarized as follows:

Spatial Navigation: users should be able to easily navigate to desired places or objects of the environment. Therefore, designers should consider usability guidelines for navigation in 3D environments (e.g. [21]) and should include navigational aids, such as mini-maps and landmarks.

Social Navigation: users should be able to chat with each other, to participate in group discussions, to see where other users are located and to be informed about current and past actions of other users.

Semantic Navigation: users should be able to search for artifacts, other users or group activities based on desired concepts. Furthermore, the concepts should be dynamically linked with external information sources from the internet, in order to allow for further searches.

The proposed framework attempts to address these needs by introducing a number of novel features that extend VWs' functionality. Such features are outlined below.

A. Thematic discussions

Erickson and Kellog [22] claim that knowledge communities can be supported by providing the necessary means to support "long running, deep and coherent conversations". They believe that users should be able to "search, navigate and visualize their conversations" and they suggest that knowledge production and use "will proceed most easily in a semiprivate environment". The authors agree with this approach and propose an application in the context of VWs through the metaphor of "*thematic discussions*". A thematic discussion can be initiated by any user and can be associated with one or more concepts of the domain ontology. It is visualized as a region drawn on the ground and only users that place themselves within this region are participating in the discussion; all other users are not reading the discussion messages (Fig. 2). A discussion becomes inactive if there is no chat activity for a long period of time and it no longer exists in the environment. Furthermore, all activity that takes place within the discussion is logged and may be recalled later even if it is deactivated. Users may reactivate a past discussion if they wish.

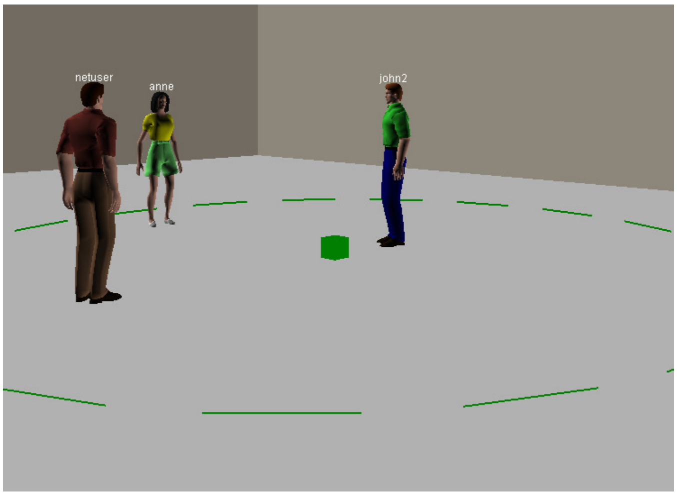

Figure 2. Users participating in a thematic discussion.

The differences between the proposed concept of thematic discussions and of emergent group discussions that may take place in any VW are the following:

1. *Thematic discussions are semi-private*: any user can be aware of an ongoing discussion and any user may enter or leave a discussion, but only users that are within the discussion area are reading each other's messages.

2. *Thematic discussions are logged*: users can read the contents of past discussions and may re-activate them on demand.

3. *Thematic discussions are associated with domain concepts*: users are informed about the topics of the discussion and so they can decide whether to join or not, based on their interests. Furthermore, they can search for ongoing or past discussions based on domain concepts as we shall describe later.

B. *User trails and tags*

A basic prerequisite for social navigation is to have an awareness of other users' actions and opinions. Ideally, this awareness should include not only directly perceivable events, but also past user actions. In order to satisfy these requirements, we adopt two metaphors that are quite popular in today's web pages and apply them in the context of Thematic Virtual Worlds: a) users may optionally add tags in places, information artifacts or discussions, and b) they leave trails of their motion in the environment (Fig. 3).

The use of tags lets users know what others are thinking or suggesting about the environment. Tags have been used in collaborative virtual environments in the form of 'annotations' to support asynchronous communication between collaborators (e.g. Immersive Redliner [13]). Given the fact that if a lot of tagged elements exist concurrently in the users' field of view their labels will take up much space blocking the view of the 3D environment, designers have to use rules to limit the number of tags being displayed. In our implemented environment tags are rendered as labels associated to the element they refer to, and they are being displayed only if the user clicks on an artifact or discussion.

Figure 3. Visualization of user trails.

The visualization of trails is a way to understand the places the majority of users have been moving to and the elements they have been looking at. The environment keeps log of users' motion and their paths are visualized as continuous lines drawn on the ground. The concurrent presentation of a number of user trails provides rich visual information about the popular places of the environment as well as the navigation routes that users have been using in the environment. User trails are visualized upon user request and may be filtered based on specific subjects. E.g. one may see only the trails of users interested in a given subset of the domain ontology.

C. *Semantic filters*

The traditional metaphor of semantic navigation in the Web is the following of hyperlinks from one page to another with relevant content. In the case of VWs, however, where the elements have certain location in the 3D space and user navigational model is spatial, new means of representation have to be adopted. The use of teleportation links from one place to another could be one possible approach. However, frequent use of teleportation as a means of navigating in a VW has been accused as causing disorientation and distortion of the users' sense of presence.

The proposed solution is the use of semantic filters as a metaphor for semantic navigation assistance (Fig. 4). The concept of semantic filters is the following: at any time the user may select a subset of concepts from the domain ontology and set them as filters. These filters are then used to search one or more of the following elements: information artifacts, users currently online, active and past discussions, user trails.

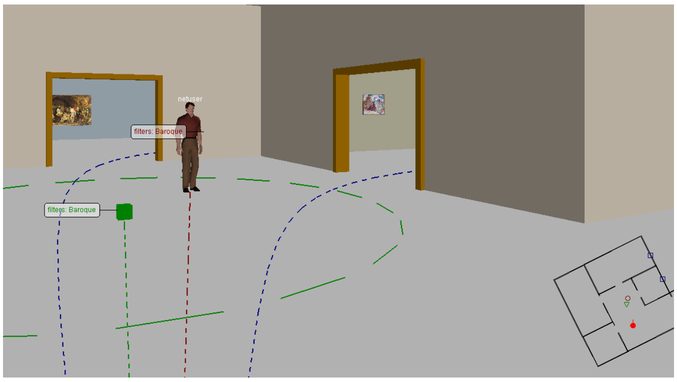

Figure 4. Visualization of semantic search results for users, discussions and artifacts related to 'Baroque'.

In the first three cases, the visualization of the search results is using color coding to distinguish between the three types of elements (artifacts, users and discussions). For each element that matches the given filters:

a) A safe (collision-free) path is drawn on the ground from the user's point of view to the element.

b) The element is being marked on the mini-map.

c) A label is attached to the element displaying the concepts it is associated with.

Finally, in the case of user trails, only the trails of users whose interests match the semantic filters are being drawn.

D. *Interface with Linked Data*

The proposed framework supports interoperability between the VW and the wider information space it belongs, which may consist of other VWs or external information systems containing possibly useful information for the visitors. Such interoperability is powered by linked data technologies.

Linked data is part of the wider concept of the semantic web, as described by Tim Berners Lee in [23]. Essentially, the idea of linked data is governed by four 'rules'[2]:

1. Use Uniform Resource Identifiers – URI as names for things.

2. Use active URI so that people can look up those names.

3. When someone looks up a URI, provide useful information, using semantic web standards (e.g. Resource Description Framework – RDF, SPARQL Protocol and RDF Query Language – SPARQL).

4. Include links to other URIs, so that users can discover more things.

Resources that are available as linked data are now being integrated to provide experimental knowledge bases containing both general purpose knowledge as well as a host of specific facts about significant people, places, organizations, events and many other entities of interest. The results are finding immediate applications in many areas, including improving information retrieval, text mining, and information extraction [24].

Along these lines, DBpedia[3] emerged as an effort to realize the vision of linked data. More specifically, the authors of [25] transformed the semi-structured information contained within Wikipedia to RDF, stored it in accordingly designed repositories called 'triplestores' and made it publicly available as data dumps[4]. Moreover, they provided a query interface to their triplestore (i.e. SPARQL endpoint) in accordance to the aforementioned linked data rules.

The emergence of DBpedia inspired many other organizations to follow similar actions in order to make their own data publicly available. The employment of URI as identifiers of the resources that are available as linked data enabled diverse triplestores to reference each other's resources, thus realizing the linked open data cloud[5].

In order to apply the above principles in a VW, we make the assumption that a VW is yet another information space, where users interact with each other and with various items of the surrounding environment. The outcome of such interactions is the production of information. Semantic web standards such as URI, RDF and SPARQL should be employed in order to store such information in a way that it is usable from other information spaces outside the VW. At the same time, a 'linked data ready' VW should be capable of providing its visitors the opportunity to look for 'interesting' information outside the strictly defined borders of the VW per se. In order to accomplish such a task, the Graphical User Interface – GUI should be able to translate the visitors' requests for information during their presence within the VW, to appropriate queries (e.g. SPARQL queries). Such queries should be accordingly addressed to suitable linked data repositories that act as external information spaces. The corresponding responses should be tunneled back to the GUI, which is responsible for the visualization of the information in a way that is easily comprehensible from the visitors that addressed the initial query. It should be noted that the complexity of the information exchange with the external information spaces should be hidden from the end users.

E. *Architecture*

The proposed framework is based on a 3-tier architecture (Fig. 5). User clients are connected to the VW server – VW server, which is responsible for the synchronization of the multi-user 3D environment, and all data management processes take place at the Linked Open Data server – LOD server, which provides the interface between the VW and the linked data.

As discussed earlier in this paper, the proposed framework is based on linked data technologies. More specifically, the LOD Server consists of a triplestore (containing all the information that is available to the VW) and an access point capable of answering SPARQL requests from third party applications. The access point essentially transforms the LOD Server to a data provider, since it makes available the

[2] Linked data: http://www.w3.org/DesignIssues/LinkedData.html, [accessed: 13.1.2011]

[3] DBpedia: www.dbpedia.org, [accessed: 4/1/2011]

[4] DBpedia dumps: http://wiki.dbpedia.org/Downloads36, [accessed: 4/1/2011]

[5] LOD cloud: http://lod-cloud.net, [accessed: 4/1/2011]

information that is stored within the triplestore to other, LOD-ready applications.

Information exchange between the triplestore within the LOD server and the VW server is facilitated through the employment of an accordingly designed protocol. The LOD server accepts requests from the VW Server and replies with suitable responses. There are two types of requests that can be addressed to the LOD Server: SET requests and GET requests. SET requests add data to the triplestore and GET requests query the triplestore.

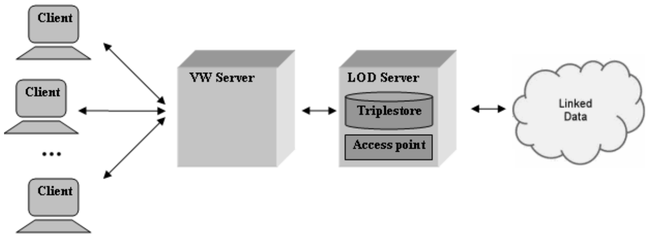

Figure 5. Proposed architecture

Interaction with other applications on the Web that are also compatible with linked data technologies is facilitated through accordingly designed requests. For example, a request for related information on a given subject could be addressed to DBpedia's SPARQL access point[6], which, in turn replies with related hyperinks coming from various data providers. The hyperlinks are tunneled back to the VW server which, in turn, transmits them to the clients for visualization. In a similar manner, another VW that is equipped with linked data technologies could address SPARQL queries to the access point of a VW that is based on the proposed architecture and accordingly acquire the desired information. Such information originating from the "source" VW could be integrated to the environment of the "target" VW that issued the initial query. This way, part of a VW would correspond to information originating from another one, facilitating this way interoperability between diverse VW.

IV. Prototype Implementation

We have created a prototype implementation of the proposed Thematic Virtual Worlds framework and used it to set up a case study in order to perform an initial user evaluation of its usability and performance. The case study is a virtual gallery containing famous paintings of the 19th and 20th century. Visitors are able to browse the gallery, discuss with each other, perform semantic searches, and lookup information about the artistic movement or style of each painting in related information sources through the employment of linked data. Moreover, external information spaces are able to make requests about the information that is stored within the virtual gallery in the form of linked data (i.e. triplestore) by taking advantage of suitable semantic web technologies (i.e. SPARQL endpoint). Figure 6 presents a screenshot of the case study.

[6] DBpedia's SPARQL endpoint: http://dbpedia.org/sparql [accessed: 4/1/2011]

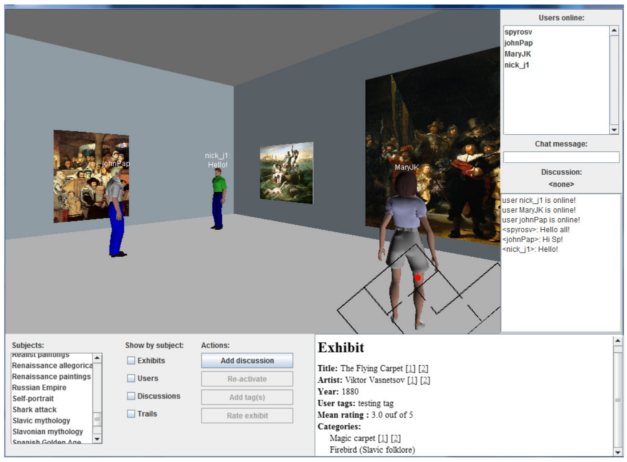

Figure 6. Screenshot of the prototype.

In order to setup the case study, we have selected 40 images of well known paintings with public domain license and modeled an equal number of VRML models presenting them in a canvas with their original dimensions. We associated each painting with a number of categories concerning the artistic movement it belongs to, its subject, and the technique being used. The set of all these categories formed our domain ontology; visitors of the virtual gallery could declare one or more of them as their interests, use them in semantic searches, or add new discussions about them. Finally, we modeled a large interior space as exhibition hall and arranged the exhibits in its rooms based on the artistic movement.

The implemented prototype is integrating a number of technologies. The client has been implemented as a Java application running over the Web using the Java Web Start technology. All 3D models are stored in VRML format and the visualization process on the client applications is using the Java3D library and the java3d-vrml97 loaders to import and visualize the models. The VW server is a java application that communicates with the clients using standard TCP/IP sockets and a dedicated communication protocol that supports the message exchange presented in 3.5. Furthermore, it posts XML Requests to the LOD Server and accordingly receives XML Responses using the Apache Commons libraries.

The triplestore within the LOD server stores all information in Notation 3 - N3 format[7]. More specifically, the triplestore contains facts represented as triples containing 3 entities: subject, predicate and object. Each entity is expressed as a URI belonging to an accordingly defined namespace (i.e. http://vw.org) or a literal.

For example, the triple:

```
<http://vw.org/resource#impressionism>
<http://vw.org/property#type>
"topic" .
```

indicates that the resource 'impressionism' is a topic, whereas the triple:

```
<http://vw.org/resource#spyrosv>
<http://vw.org/property#interestedIn>
<http://vw.org/resource#impressionism> .
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[7] N3: http://www.w3.org/DesignIssues/Notation3.html [accessed: 4/1/2011]

indicates that the resource 'spyrosv' is interested in the resource 'impressionism'.

Information exchange between the triplestore and the VW server is facilitated through the employment of a protocol encoded in custom XML format. The protocol is implemented in Python and it is based on the RDFLib library[8]. As discussed earlier, there are two types of XML requests that can be addressed to the LOD Server: SET requests and GET requests. Each request is expressed as an XML message, which is addressed from the VW server to the LOD server. The request is addressed to DBpedia's SPARQL endpoint, which, in turn replies with three related hyperinks coming from umbel.com, rdf.freebase.com and wikipedia.org respectively. The three hyperlinks are tunneled back to the VW server which, in turn, delivers them to the client that initiated the entire message exchange.

V. EVALUATION

We set up a user evaluation of the case study in order to test the performance of the prototype with a number of concurrently connected users, to assess the usability of the proposed metaphors, and to gain empirical observations from the usage of the environment. The evaluation scenario was the following: we asked the users to register to the system and to declare their interests by selecting a subset of the domain categories. Then, we let them concurrently connect to the environment. We spent 5 minutes in an introductory session, in which the functionality of the environment was explained and demonstrated. After that, we let them experiment on their own with the environment and instructed them to do the following:

1. To browse the collection of paintings, find at least three paintings that match their interests and tag them.
2. To try and find other users with similar interests and/or visualize their trails.
3. To participate in a discussion about a major artistic movement.

The session lasted 30 minutes, during which all users' movements and actions were logged by the VW server. After that, the users were asked to complete a questionnaire in order to assess their opinion about each of the semantic and social navigation features of the environment and of the system in general. Finally, the users were interviewed in order to provide further comments and suggestions.

A group of thirteen users (four male and eight female) participated in the evaluation process, all of which were undergraduate students of the department of Product and Systems Design Engineering, University of the Aegean. Initially, the users were asked to record their experience in first-person navigation (e.g. from playing computer games) in a 5-level Likert scale. Four of them declared that they were highly experienced, whilst the rest of them had medium or little experience. No user reported having no experience at all.

The overall performance of the system during the evaluation session was satisfactory. There were no problems by the concurrent interaction of all users, as the refresh rate of the client environments was not significantly decreased by the introduction of a multitude of animated avatars. However, delays were noted during the login procedure and during the request for additional information about the paintings, caused by the increased traffic between the VW server and the LOD server.

During their interaction session, users seemed to have little difficulty in understanding the new metaphors. They used the semantic search tool quite often (on average 9.3 times per user) in order to find paintings that were related to categories that captured their attention. Also, they easily managed to detect the search results on the mini-map and to follow the drawn paths in order to approach the items. Three new discussions were generated, but the dialogs were short and typical given the limited time of the interaction session. A large number of the paintings (29 out of 40) have been tagged by users. Most of them were comments about their aesthetic quality. All users visited at least three external links related to the paintings, mostly concerning the creator's biography or information about the artistic movement. Finally 10 out of 13 users requested to see the trails of other users with similar interests and attempted to follow them to see what they have visited.

Users were asked to comment on the usefulness of the introduced features for VWs containing information artifacts (e.g. 3D digital libraries, virtual museums, educational environments, etc). They replied in a 5-level Likert scale, with 1 meaning not useful at all and 5 meaning very useful. The results are summarized in Table 1.

TABLE I. RESULTS ABOUT THE USEFULNESS OF THE METAPHORS.

Features	Average value in 5-level Likert scale (1=not at all, 5=very)
Thematic Discussions	3.31
User Trails	3.62
Semantic Filters	3.85
External linking	3.38

Users were also asked to assess their difficulty in detecting the search results of semantic filters using the same scale (1 meaning impossible and 5 meaning very easy) and the mean value of their answers was 4.3. Finally, users were asked to rate the system in total in terms of its usefulness as a platform for Thematic Virtual World and their mean rating was 4.15.

Most user comments focused on the general usefulness of the platform, as well as of the problems they encountered during their interaction. Two users commented that they experienced difficulties in navigation. One of them explained that it was difficult to maneuver his/her avatar in order to position himself correctly to have a good view of the paintings. Another user commented that the image quality of the paintings was low, so he/she missed some interesting details. In order to address this issue, an extra option should be added to the user interface, enabling users to view another version of the painting with higher resolution. On the other hand, some users commented that the idea is very interesting, especially if applied in educational environments, and one user made the following comment: "a very useful application, because the user can have a very good initial idea about the exhibition

[8] RDFlib: http://www.rdflib.net/ [accessed: 4/1/2011]

he/she wishes to visit, mark the places with interesting exhibits and any related information that he might like to view, so that he doesn't have to read brochures before entering the physical space of an exhibition" (translated from Greek). Finally, the majority of users were fairly enthusiastic about using the system and some of them asked whether there are other similar 3D environments of online museums and galleries worldwide.

VI. CONCLUSIONS

In this paper, we have introduced the concept of the 'Thematic Virtual World' as a VW related to a certain subject that aims to bring together people interested in it. During their presence in the VW, visitors acquire and exchange information from their interaction with the environment and with each other. A Thematic Virtual World contains metaphors that underpin the semantic and social aspect of this particular environment.

The implemented prototype provides the functionality that derives from the intersection of three different spaces, namely the semantic space, the 3D space and the social space. More specifically, the virtual gallery introduces thematic discussions as a special kind of group discussions featuring semi-privacy, logging, and association with domain concepts. Also, user trails are supported, giving this way the opportunity to visitors to follow other visitors that exhibit similar interests. The virtual gallery avoids information overload of the VW by introducing a number of semantic filters that give the opportunity to visitors of the gallery to filter paintings, online users, active and past discussions and user trails. Finally, visitors of the virtual gallery are able to gather information from other, external information systems through the employment of linked data technologies. At the same time, other VWs or information systems are able to query the information that is stored within the virtual gallery. The results of the evaluation were rather encouraging and pointed out the need of open, interoperable VWs that support social and semantic activities for their users.

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